OPERATIONAL CHARACTERISTICS OF A MICROWAVE LANDING SYSTEM

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ABSTRACT

A brief description of the glide slope, localizer, and aircraft equipment comprising the Microwave Landing System is given. The operational requirements of a radio landing system as set forth by ICAO are presented and the operation of the Microwave Landing System is compared with these requirements. Typical manual and automatic flight recordings are shown and discussed.

This article is revised to include applicable recommendations of Special Committee 31 of the RTCA, and nomenclature of Special Committee 24 of the RTCA.

During recent months the problem of safely landing aircraft in bad weather has received considerable publicity. This article is presented to describe equipment briefly and to give operational data on a microwave landing system. The equipment to be described has been under development for approximately eight years, and the specific equipment described has been in operation for one and one-half years. This system has been tested successfully at various airports, among which are Pittsburgh; Harrisburg; Westerly, Rhode Island; Banana River, Florida; and La Guardia. The surrounding terrain of these airports imposes severe requirements on any instrument landing system.

It is desirable to differentiate between so-called instrument landing systems and instrument approach systems. An instrument approach system is one which provides the pilot of an aircraft with all of the information necessary to reach a position, within given tolerances, relative to the touchdown area. An instrument landing system is one which provides all of the information necessary for controlling the aircraft by manual or automatic means from the point where the guide beams are intercepted to a full stop on the runway under conditions where the pilot's vision is zero beyond the windshield. As the result of a large number of flights, the conclusion has been reached that instrument landing must eventually be fully automatic. The Microwave Landing System will now bring an aircraft over the touchdown area and 5 to 25 feet above the runway. The system is constructed so that this touchdown area is reached under all service conditions of weather, cross winds, terrain, and objects on the airport. Variations in operation are known to exist, such as effects of ground reflections on the glide slope* and instabilities in transmitting and receiving equipment, but these variations do not exceed the operational tolerances.

In 1938 the invention of the Klystron microwave tube opened up a new region of the radio spectrum for practical use and for the first time gave a tool which would allow the construction of a satisfactory landing system. From original experiments at 40 cm., the present system has evolved through five generations of equipment to the present 11.35 cm. (2640 Mc.) System.

The Microwave Landing System is a fixed-beam-type system incorporating a glide slope and a tone† localizer installed on the airport and airborne receiving equipment in the aircraft. The glide slope trailer has an antenna which is a twelve-foot-high section of a cylindrical parabola fed in such a manner that two narrow beams overlapping in the vertical plane are transmitted into space. These two beams are formed by feeding the parabola off focus from two separate wave guide feeds. The equi-signal intersection of these beams forms the glide plane. The angle of the glide plane can be varied from 2½ to 4° by tilting the whole trailer and antenna system using the supporting jacks. The angle

* RTCA–AC31 recommends the term "glide slope" in preference to "glide path."

† Also RTCA preferred nomenclature.

of glide slope is set up optically and can be measured by the sensitive spirit level mounted on the side of the parabola.

The vertical localizer plane which lies on the centerline of the runway is produced by the equi-signal intersection of two beams transmitted from the split paraboloid. The two side antennas provide side coverage for the system.

Reflections from the ground, hangars, and other reflective objects are minimized through the use of narrow beams, which allow the major part of the energy to be directed where desired. Because of this, siting problems are reduced to a minimum. Both the glide slope and the localizer can be set up by optical means. For accomplishing this, theodolites are installed in each trailer. These instruments are used not only to set the equipment up, but also to track the aircraft in flight during tests of the system. As can be seen, the ground equipment is mobile. Time tests have shown that two men can move the system from one runway to another and have the equipment on the air ready for flight in seventy minutes.

Figure 1 shows the construction of the transmitter used in both glide slope and

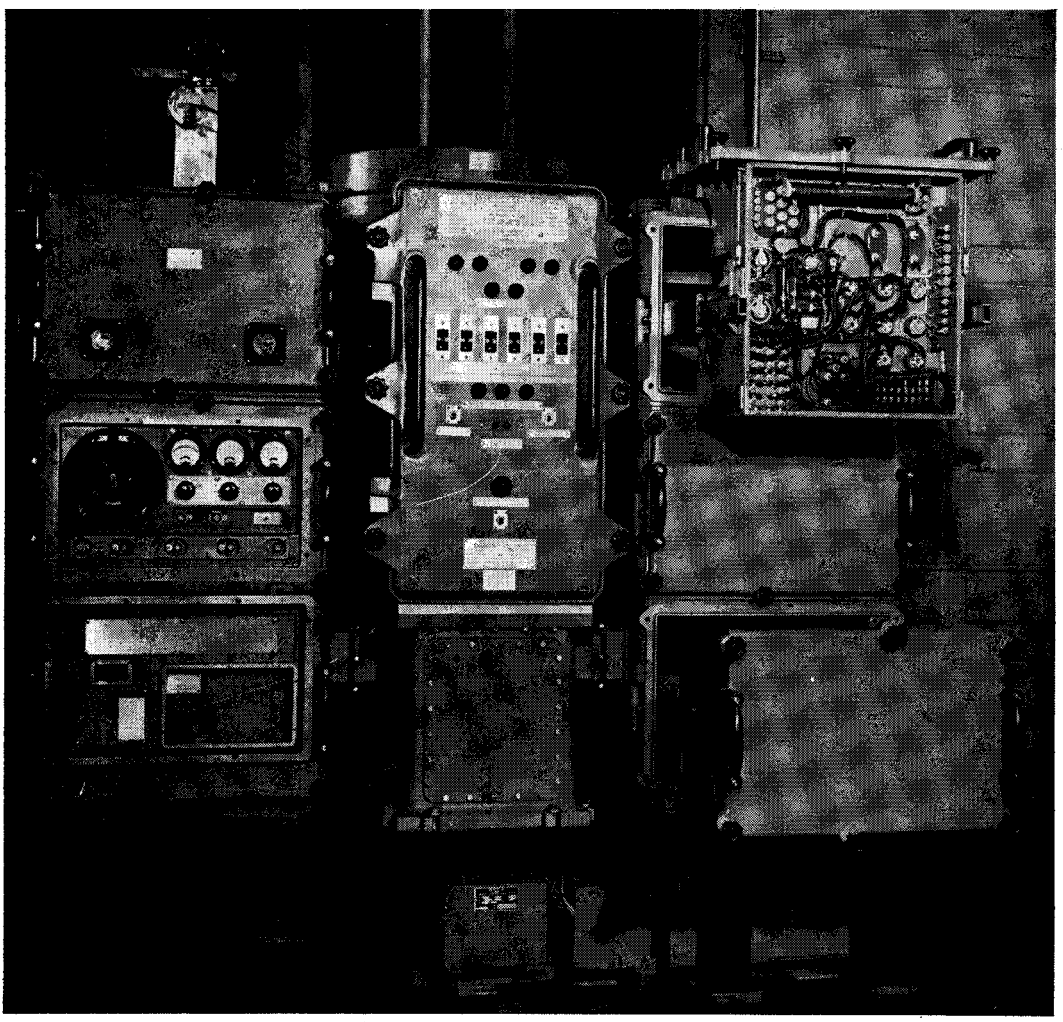

FIG. 1.—Glide slope and tone localizer transmitter.

tone localizer. This is a crystal controlled transmitter which delivers 70 watts of c-w. power at a frequency, in the case of the localizer, of 2640 Mc., ± 0.0005%. The corresponding glide slope channel operates at 2617 Mc. The unit was designed to be rugged and to provide ease of servicing. Both of these features are illustrated in the photograph. For an application such as instrument landing, where the most severe operating conditions occur at the time when the equipment is needed most badly, the equipment cannot be too substantial.

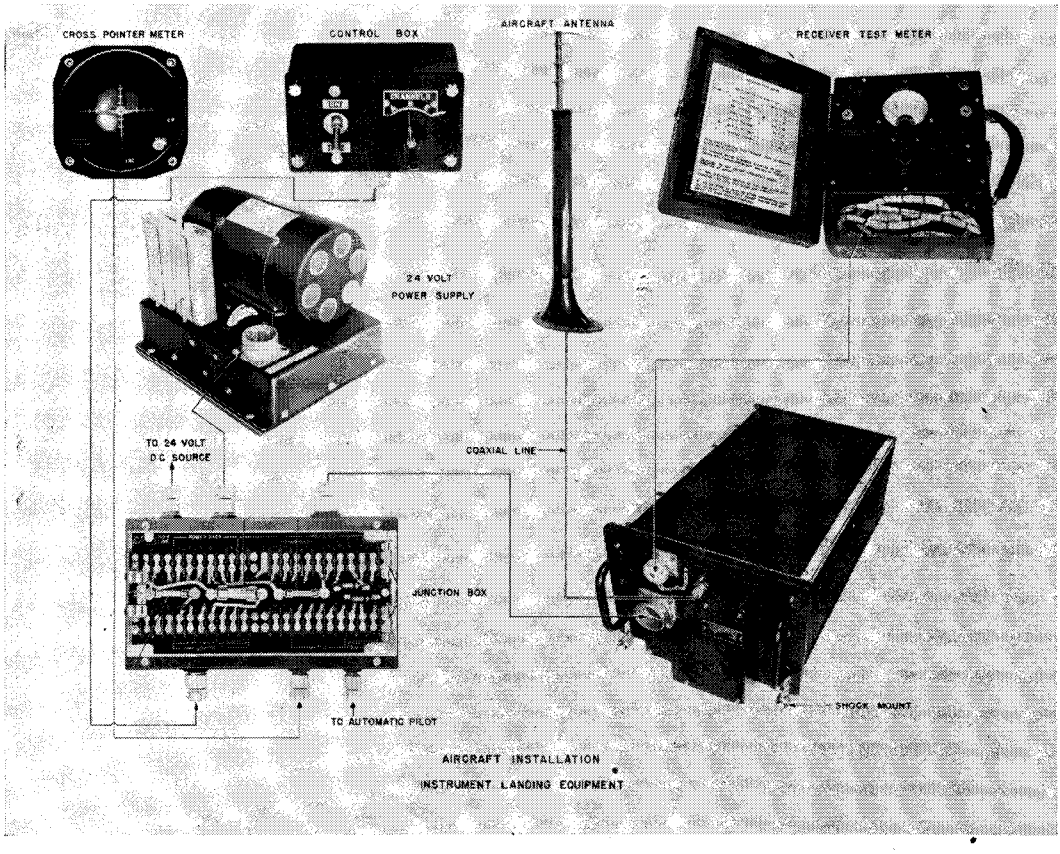

FIG. 2.—Aircraft installation instrument-landing equipment.

Figure 2 shows the aircraft equipment. Pictured in the photograph are the box, junction box, the pilot's flight-path deviation indicator‡ (a spherical-type meter with safety alarm flags or alarm lights), the aircraft antenna, which is mounted on top of the aircraft and provides 360° azimuth coverage and ± 20 vertical coverage, the combined glide slope and tone localizer receiver, receiver power supply, and the serviceman's test meter. Because the frequencies of glide slope and localizer transmitter are close, a single antenna, antenna cable, and receiver local oscillator can be used for the two services. Safety alarm lights or flags on the flight-path deviation indicator monitor the landing system and will indicate to the pilot failure of either airborne or ground equipment.

The Special Radio Technical Division of ICAO, at its meeting in Montreal, November 1946, set up operational requirements for radio aids to navigation. In addition to

‡ RTCA nomenclature preferred in place of "cross-pointer meter."

other aids the committee report covers specifications for operational use of radio aids to final approach and landing. It is desired here to present some of the requirements set forth by ICAO and to compare the operation of the present Microwave Landing System with these requirements. Certain paragraphs of this committee report are quoted below:

(1) The navigational aids provided for final approach and landing shall make it possible to fly an aircraft safely down a pre-determined approach path to a landing or alighting on water terminated by a normal stop. (2) The system shall provide to the pilot: (*a*) Precise continuous visual indications of the displacement of the aircraft relative to the pre-determined approach path. (*b*) Immediate and positive indication of malfunctioning of any part of the system. (3) The system shall be capable of providing for either automatic or manual flight to a landing. (4) The system shall not be the limiting factor in the determination of traffic handling capacity of the final approach zone and aerodrome.

The touchdown area is defined as "a rectangular portion of the runway surface near its approach end within which lies the optimum point of contact at which the aircraft should touchdown when landing." Assuming an average runway of 5,000 feet length and 150 feet width, the touchdown area will be 800 feet long and 90 feet wide. With the Microwave Landing System, or other stable straight-line glide slope system, the point "P" which is specified as 800 feet from the end of the runway will remain fixed for a given aircraft antenna height above the ground. This point, however, will vary directly with varying antenna height. For example, if the point "P" 800 feet from the end of the runway is obtained with a DC3 (antenna 18 feet above the ground), P will

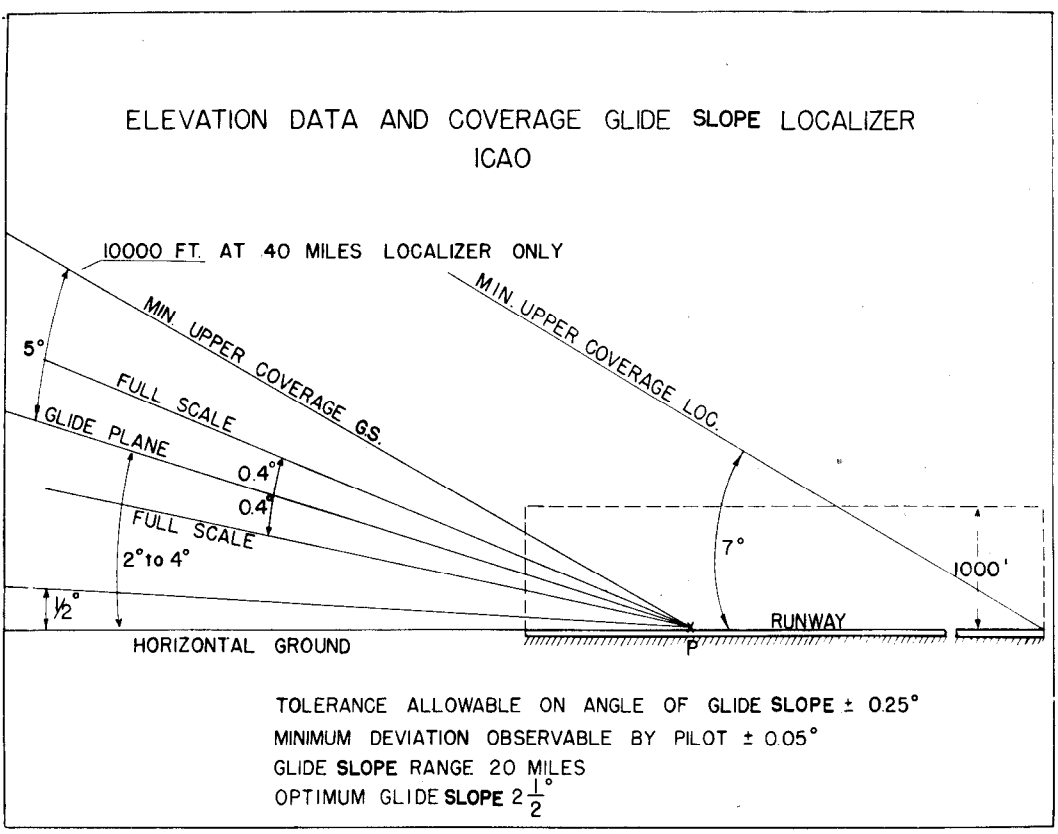

FIG. 3.—ICAO requirements for elevation coverage and accuracy of the glide slope and localizer.

be 680 feet with an antenna 24 feet high, and 565 feet with an antenna 30 feet high.

In addition to the general requirements outlined above, detailed limitations and accuracies for a glide slope and localizer have been set up. The following drawings illustrating angular requirements and data are not to scale.

Figure 3 presents the ICAO requirements for elevation coverage and accuracy of the glide slope and localizer. It is required that the glide slope have a coverage from a minimum of ½° above horizontal to 3° above the glide plane. The glide plane should be adjustable from two to four degrees above horizontal. Full-scale fly up to full-scale fly down meter action should be obtained in ± .4°. The tolerance allowable on the angle of the glide slope under all service conditions is ± ¼°. The minimum deviation observable by the pilot from which he should make a correction to return to the proper path is ½°. The glide slope range shall be at least 20 miles.

The vertical coverage of the localizer shall be between ½° above the horizontal as measured at the approach end of the runway and 7° above horizontal as measured at the opposite end of the runway. Coverage is required up to 1,000 feet above the landing area.

Special Committee 31 of the RTCA has set up requirements which differ somewhat from the above. Their differences are noted as: (1) Full-scale fly down shall be obtained in ± 0.5°. (2) The glide slope coverage shall extend from ½° to 20° above horizontal. (3) The glide slope shall be adjustable from 1¾° to 4°. (4) The service range of the glide slope shall be 15 miles.

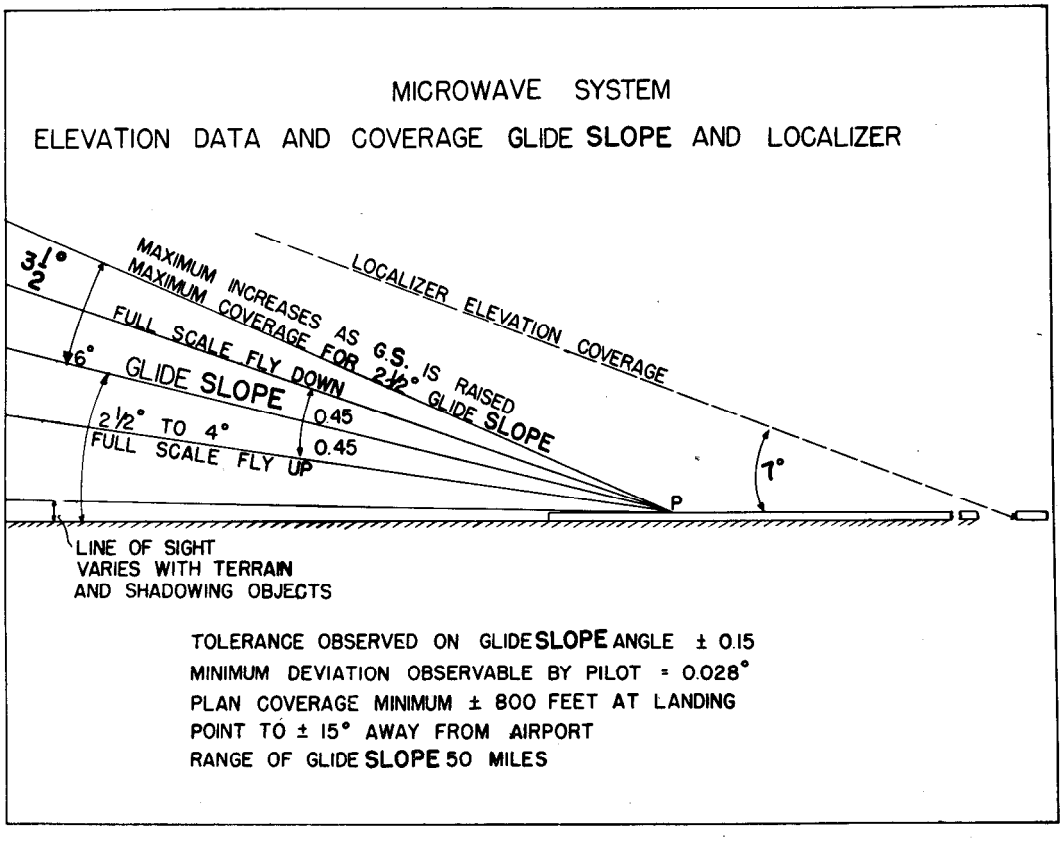

FIG. 4.—Microwave system, showing elevation data and coverage glide slope and localizer.

Figure 4 shows the elevation coverage and accuracies available on the Microwave Landing System. The localizer elevation coverage is 5° from the localizer trailer, not from the end of the runway. Coverage to 1,000 feet is not provided over the landing area. The glide slope vertical coverage is 3½° above the glide plane and the lower limit of coverage of both glide slope and localizer is determined by line of sight. Shadows of trees, hills, etc., will determine the lower angle of coverage. The glide slope is adjustable from 2½° to 4°. The course width full-scale fly up to full-scale fly down is ± 0.45°. The tolerance obtained on the glide slope angle under all service conditions is ± 0.15°. It is estimated that the minimum deviation observable by a pilot is 1/35°. The service range of the glide slope is 50 miles.

Figure 5 shows the azimuth coverage and accuracy requirements for the glide slope and localizer as set up by ICAO. It specifies that the glide slope plan coverage shall be ± 8° as measured from the intersection of the glide plane with the runway. In the localizer the coverage shall be ±45° as measured from the localizer transmitter. Full-scale fly left to full-scale fly right shall be obtained on the localizer from ±2° to 4° from the "on course" position. The tolerance allowable in "on course" position is ±½° while the minimum deviation observable by the pilot shall be ±¼°. In addition a failure warning area is provided which covers an area of 360° in azimuth out to one-half the maximum range of the system. The range of the localizer shall be at least 40 miles.

RTCA differences in the localizer are as follows: (1) The localizer coverage shall be ±60° as measured from the transmitter. (2) The region of quantitative indications shall be ±5°. (3) The accuracy of the "on course"

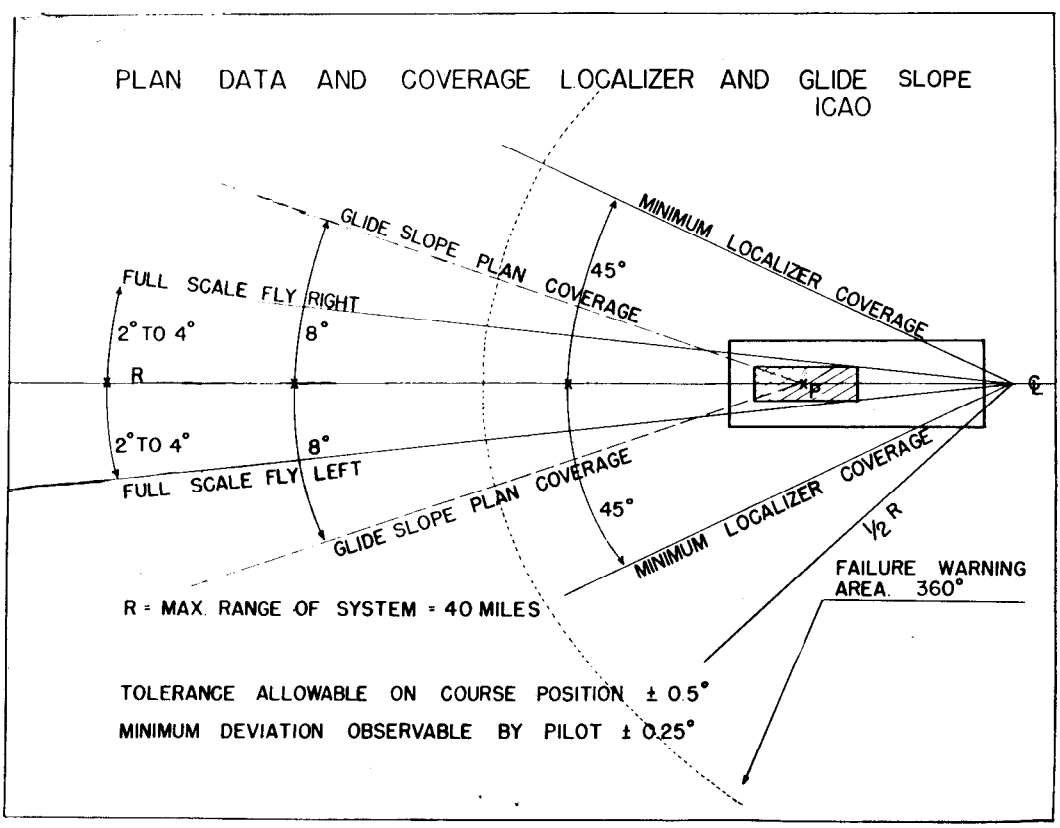

FIG. 5.—ICAO plan data, and coverage localizer and glide slope.

position shall be $\pm\frac{1}{4}°$. (4) The system must allow a landing rate not less than three aircraft per minute.

Figure 6 shows the available coverage and accuracies in azimuth on the Microwave Landing system. The glide slope plan coverage is a minimum at the landing point and at that point is ±800 feet from the transmitter. This increases to ±15° 3,000 feet from the transmitter. The microwave localizer provides coverage up to ±85° to the course, and full-scale fly left to full-scale fly right meter indication is obtained with a deviation of ±1.45° from the course. The tolerance observed in "on course" position under all service conditions is ±45°, and it is estimated that the minimum deviation observable by the pilot is ±0.14°. The service range of the localizer is 50 miles.

Tests have been made on the approach path in the touchdown area on the glide slope, as this is considered the most important point of the whole approach and landing. The theoretical glide plane is a perfectly flat line terminating at the center of the antenna structure. Measurements show this to be correct only when flying directly into the transmitter. When flying to one side or the other of the transmitter, as is necessary in actual operation, the characteristics are different. The measured course and measured course widths when landing 500 feet

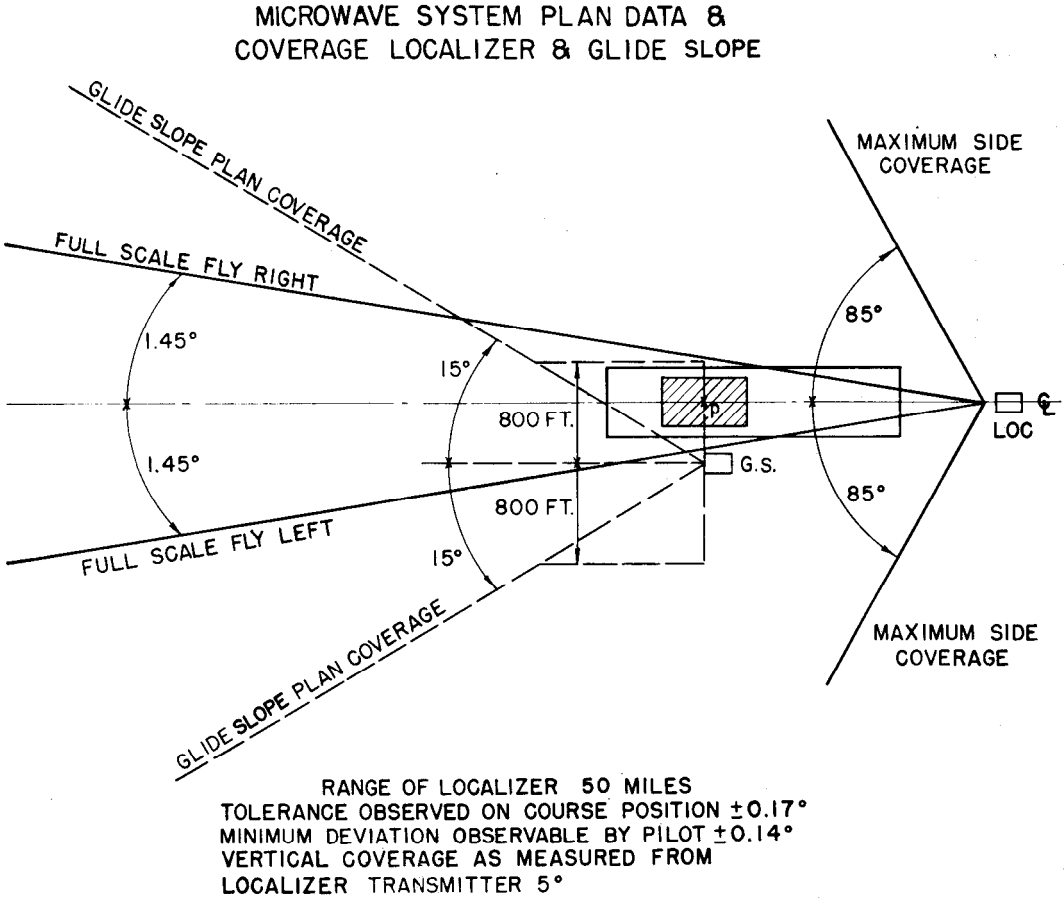

FIG. 6.—Microwave Landing System plan data, showing available coverage and accuracies in azimuth.

to one side of the transmitter indicate that the course tends to flare out slightly at the approach end. The course width also flares and actually has finite width at the lowest point of approach.

When speaking of the Microwave Landing System, it has been stated that ground reflections are minimized and are negligible. This is not strictly true. In the case of the localizer, ground reflections do have negligible effect. In the glide slope, ground reflections may affect the course. This effect is small, however, and does not limit the usefulness of the system, as the glide slope always terminates in the touchdown area. The slight flaring noted, together with the increased angular width of the course at the touchdown point, is due in part to the ground reflections.

There are additional effects of ground reflections on the glide slope. Curves were obtained by flying at a constant altitude through the glide plane (see Fig. 7). The value plotted is flight-path deviation indicator current and shows, when going from left to right on the slide, the aircraft flying from full-scale fly up to full-scale fly down. Curve A is the course characteristic obtained with negligible ground reflections or when the angle between the glide plane and the ground is 2½° or greater. When the angle between the glide plane and ground is 20°, curve B is obtained. The reflections have introduced a flat spot near the "on course" crossover. The angular width of this flat spot is about 0.2°. When the ground is 1.75° below the glide plane, the crossover will appear as in curve C. In this case the flat spot appears in the same angular position above the ground; however, it has moved to a point with respect to the course where it is no longer apparent on the cross-pointer meter. This causes the course width as measured full scale to full scale to change from .9° to

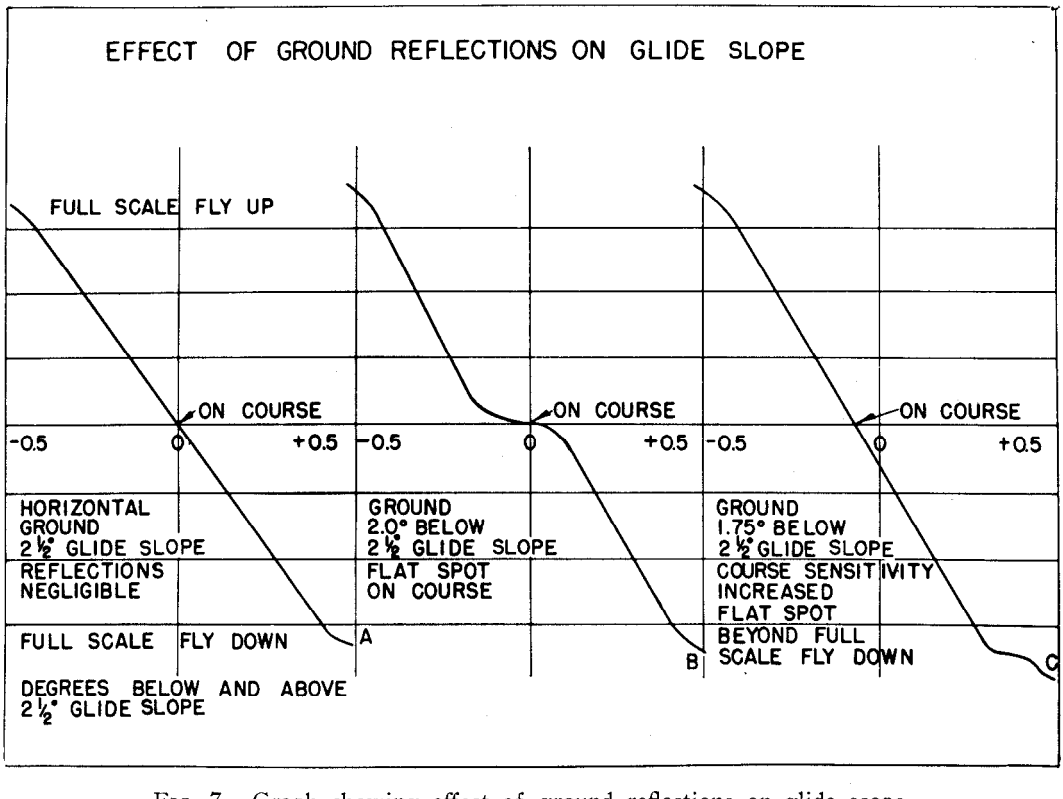

FIG. 7.—Graph showing effect of ground reflections on glide scope.

.6°, and the position of the course to shift approximately 0.15°. This means that if the glide slope is set up on ground which is sloping upward from the transmitter, the course can be shifted slightly from 2½°; the sensitivity may be increased, or the full-scale to full-scale characteristic of the course as seen on the cross-pointer meter may not be linear. Whenever the angle between the ground and the course is 2½° or greater, the ground reflections vary little from wet ground to dry ground. Therefore, a given installation does not change its characteristics from day to day, regardless of weather conditions.

LOCALIZER OPERATION IN TOUCHDOWN AREA

The localizer provides a course within ±0.17° of the center line of the runway from the transmitter to the touchdown point. Assuming 5,000′ between the transmitter and the touchdown point, this accuracy is ±15′ at the touchdown point. Accuracy along the runway is important when considering complete landing in zero visibility conditions.

The present ground equipment has operated 6,000 hours. During this time some electrical failures have occurred. During the 6,000 hours of ground-station operation about 450 hours of flight have been made. These flights were made specifically for test or demonstration of the system, and represent the number of hours flying while receiving ground-station signals. In conjunction with these flights, 200 manual approaches and 400 automatic approaches, about 60 have been under 150-foot ceilings and ½-mile visibility.

One reason why it is felt that automatic approach and full automatic landing is the most satisfactory answer to the all-weather flying problem is that the accuracy of flight necessary to land on a predetermined runway area in zero visibility conditions is great. This is a difficult job even under good conditions. Much data has been taken in flight and it illustrates the comparative accuracy of manual and automatic approach. In all cases the manual flights were made under the hood. Both manual and automatic flights were tracked through ground theodolites and the data relayed via a radio link and entered on recordings being taken in the aircraft.

This data indicates that the human pilot has a tendency to hunt about the course, and the errors at the touchdown end of the runway appear considerable on a localizer approach; however, while the human pilot has a tendency to hunt about the course, the automatic pilot after its initial bracket onto the course stays within ±0.025° of the course.

This article has described briefly the present status of the Microwave Landing System. The operation of the system has been compared with the standards accepted by ICAO. Data has been presented to indicate the accuracy of flight possible when using the system in conjunction with an electronic automatic pilot.

TIMES OF SUNRISE AND OF SUNSET BY A GRAPHICAL METHOD

PAUL E. WYLIE

Knowledge of the times of sunrise and of sunset is useful for such purposes as: (*a*) the planning of naval tactical maneuvers; (*b*) determining the approximate time for dawn and dusk stellar observations in navigation; (*c*) finding the time for morning and evening colors. In each case an approximate value is adequate for the purpose involved.

The accompanying diagram gives the time of sunrise and of sunset on any day in the year, at any point on the earth up to latitudes 60° north or south.

The diagram may be used in two ways, viz:

1. The diagram is entered at the left margin for north latitudes, and at the right margin for south latitudes, with the approximate declination of the sun on the date involved;